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Nitrogen content estimation of rice crop based on Near Infrared (NIR) reflectance using Artificial Neural Network (ANN)

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Abstract

Nitrogen content is an important indicator used for monitoring and management of plant due to its role in photosynthesis, productivity as well as its effect on carbon and oxygen cycle. The research aimed at estimation of nitrogen content of rice crop based on Near Infrared (NIR) reflectance using Artificial Neural Network (ANN). ANN is a non-linear modeling tools based on statistical data. Nitrogen content was measured by laboratory analysis, meanwhile, its spectral reflectance of NIR (700 – 1075 nm) in the field was measured by using hand held spectroradiometer. Data were divided into 33 data training and 15 data testing using 3-fold cross validation. We found that organic molecules (nitrogen, water, etc) have specific absorption pattern in the NIR region. The experimental result shows that the comparison between measured and model estimation of Nitrogen content have RMSE of about 0.32. We conclude that NIR reflectance values can be used to predict nitrogen content using ANN method.

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Keywords: ANN; NIR; nitrogen; reflectance; rice plant

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1. Introduction

Rice (*Oryza sativa*) is one of the major food commodities from Indonesia. Indonesia as an agrarian country has 8 million hectares of rice fields, or 8% of the total land area of Indonesia [1]. But, the yields are not as good as expected. It was caused by various factors such as plant diseases, pests, bad management and monitoring, as well as natural disaster. In rice cultivation, monitoring activity is a very important aspect to maintain the quality of the rice plant. Rice plants that have good conditions are expected to provide a good yield.

Monitoring and management process of plant is closely associated with monitoring of biochemical processes, such as photosynthesis, respiration, evapotranspiration, and the decomposition of the existing biochemical concentrations in leaves, like chlorophyll, water, nitrogen, lignin and cellulose [2]. These processes provide an indicator of crop productivity, crop diseases and the availability of nutrients in plants [3]. Nitrogen content is a very interesting thing to be used as an indicator in the monitoring and management of the plant. This is because nitrogen has a very important role in photosynthesis process, plant productivity, and it affects the carbon and oxygen cycle [4]. Besides, over-fertilization of N is a common problem in rice production, which not only results in low N use efficiency, but also poses environmental pollution, reduced economic returns, increased susceptibility to crop lodging and diseases, and poor eating and cooking quality of rice grains [5, 6, 7, 8, 9].

NIR is closely associated with the structure of the molecule in plants [10]. All organic matter is composed of atoms such as Carbon, Oxygen, Hydrogen, Nitrogen, Phosphorus, Sulfur, and small amounts of other elements. These atoms will combine through covalent and electro covalent bond that form molecules. Due to the nature of the bond, the atoms and the molecules are moving constantly. The molecules will vibrate in NIR channel and absorb it[11]. The more organic molecules exist in an object, the more NIR will be absorbed. And, its reflectance value gets smaller.

Previous research had been done on rice plant using regressive linier with helicopter mounted NIR camera. In this research, the author tried to find a relationship between NIR reflectance with nitrogen content using regressive linier [12]. Besides, nitrogen estimation had been done on the other objects such as in sugarcane using spectroscopic image [13], nitrogen estimation on mixed canopy [3], and protein estimation using NDVI data [12]. In this research, we will estimate nitrogen content of rice plant using NIR reflectance based on ANN.

2. Method

This research consists of several steps: Data Acquisition, Data Preprocessing, ANN Modeling and Evaluation. The flow of this research can be seen in Figure 1

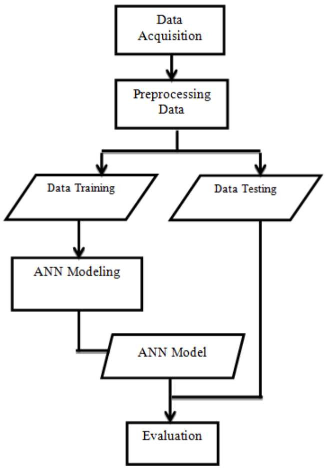

Fig. 1. Research flow

2.1. Data acquisition

In this research, we have two stages of data Acquisition; leaves reflectance measurement using spectrometer and nitrogen measurement in the laboratory. We used 48 data that had been taken in two different areas, which were Cinangeng village and IPB Dramaga research area which are located in Bogor. One data represents an area of rice fields. In this research, we randomly selected 3-point sample areas and measured its reflectance values of leaves and nitrogen content. Spectral reflectance measurement was assisted by the National Institute of Aeronautics and Space (LAPAN). While, nitrogen content measurement were aided by Department of Agronomy, Faculty of Agriculture, Bogor Agricultural University (IPB). The method used was the Kjeldahl, because it can measure organic nitrogen content like rice plant. The Kjeldahl method may be broken down into three main steps:

- *Digestion:* the decomposition of nitrogen in organic samples utilizing a concentrated acid solution. This is accomplished by boiling a homogeneous sample in concentrated sulfuric acid. The end result is an ammonium sulfate solution.
- *Distillation* : adding excess base to the acid digestion mixture to convert NH4+ to NH3, followed by boiling and condensation of the NH3 gas in a receiving solution.
- *Titration* : to quantify the amount of ammonia in the receiving solution.

2.2. Preprocessing data

At this stage, the reflectance data were selected from 700 nm - 1075 nm wavelength. In addition, we conducted an average composite of 3 sample points on each area of rice fields into an average data reflectance. So, we have 48 reflectance data. Next, the data was divided into 35 training data and 13 testing data. The process of selecting the training and the testing data was performed using the k-fold cross validation. K-fold cross validation was used to analyze the performance of the classifier.

2.3. ANN modelling

At this stage, we estimate the nitrogen content using ANN. ANN model consists of an input layer, hidden layer and output layer. The input layer consists of 376 neurons that represent the value of the spectral reflectance from 700 nm - 1075 nm wavelength. Number of hidden layer will be determined by the try-error method. Number of hidden layer would be precisely defined if the error is getting smallest.

In this research, the activation function that had been used was a bipolar sigmoid function with a range of values of -1 to +1. The bipolar sigmoid function can be determined using the following formula:

$$f(x) = \frac{1-e^{-x}}{1+e^{-x}} \quad (1)$$

2.4. Evaluation

Evaluation was conducted to test the compatibility between the values of the actual nitrogen with estimated nitrogen from ANN model. Evaluation method used in this research was the Root Mean Square Error (RMSE). RMSE is used as an indicator of error based on the total square of the deviation between the results of the model with the actual value. The formula of the RMSE is:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(N_i - M_i)^2}{n}} \quad (2)$$

Ni and Mi had been declared as actual nitrogen and estimated nitrogen content, while n stated amount of data. To determine the best model, RMSE values will average at each fold using the formula:

$$A_i = \left[1 - \frac{|y_{ai} - y_{ei}|}{y_{ai}}\right] \times 100\% \quad (3)$$

$$AvA = 1/N\,(A_i \ldots\ldots A_N) \quad (4)$$

Note:
AvA = Average accuracy
A_i = Data Accuracy in-i
y_{ai} = Actual nitrogen content in-I data
y_{ei} = Estimated nitrogen content in-i data
$\overline{y_a}$ = Average actual nitrogen content
$\bar{y_e}$ = Average estimated nitrogen content
N = number of sampleS

3. Result and discussion

3.1. Characteristics of leaves reflectance

Figure 2 shows the reflectance pattern of the paddy leaves from 400 nm-1075 nm wavelength. The reflectance values are low in 400 nm- 500 nm wavelength (blue channel) and 620 nm-680 nm (red channel) due to chlorophyll absorption during photosynthesis process. We found that organic molecules (nitrogen, water, etc) have specific absorption pattern in the NIR region. The more chlorophyll contained in a plant, the more blue and red channel will be absorbed, therefore reflectance of blue and red will be smaller. Besides, the reflectance value is relatively high at 500 nm- 580 nm. This is because the chlorophyll reflects green channel [10].

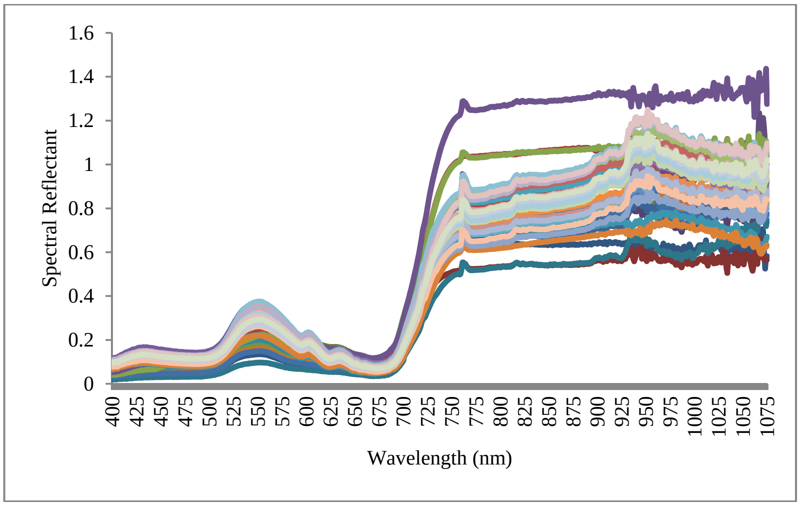

Fig. 2. Characteristics of leaves reflectance.

The reflectance value is very high at 700 nm-1075 nm (NIR channel). This is because NIR is not required by chlorophyll. So, most of NIR will be reflected. However, NIR is closely associated with the structure of the molecule in plants [10]. If more organic molecules included Nitrogen, water, etc that exists in an object, the more NIR will be absorbed. So, the spectral reflectance value gets smaller.

3.2. Nitrogen content distribution

Figure 3 shows the distribution of nitrogen content that obtained from the labolatory. From the figure we can see that 35 data are spread between 2.0% -3.0%. It was because very little data variation such as location, age, type of plant etc. Before the modeling process, data were divided into training and testing data using 3-fold cross validation.

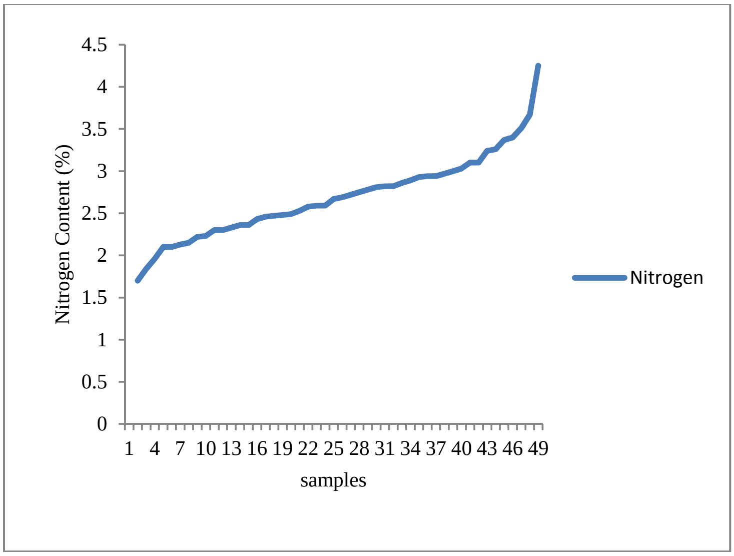

Fig. 3. Nitrogen content distribution.

Table 1 shows that the data were grouped into three groups based on nitrogen content that are LOW, MEDIUM, and HIGH. The number of samples we used in this research is 48 samples. Each group was divided into training and testing data proportionally. This process was done to maintain the balance of the data in order to obtain a more stable ANN modeling.

Table 1 Group of data sampling.

Category	Range of value	Number of Samples	Number of Training Data	Number of Testing Data
Low	1 - 2.5	19	14	5
Medium	2.5 - 3.0	19	14	5
High	3.0 - 4.25	10	7	3
TOTAL		48	35	13

3.3. Evaluation of ANN modelling

The evaluation method that used in this research was RMSE. The performance of an ANN model is determined by several variables such as the characteristics of data and the number of hidden layer. Number of hidden layer was determined using a try-error method from 5-20 hidden layers. The smallest RMSE value that had been obtained was the most optimal model. Based on the experimental results, the most optimal of hidden layer were 10, 11, and 20. Table 2 shows the RMSE value on the 3 number of hidden layer.

Table 2 RMSE value using 3-fold in 10, 11, 12 hidden layers.

Fold	RMSE		
	Number Hidden Layer		
	10	11	20
RMSE 1	0.41	0.48	0.41
RMSE 2	0.36	0.34	0.36
RMSE 3	0.24	0.16	0.25
Average of RMSE	0.33	0.32	0.34

The result showed that the most optimal model generated when the number of hidden layer is 11 nodes with the average of RMSE is 0.32. Figure 4 shows a comparison between the actual nitrogen content with estimated nitrogen content using 11 hidden layers and 3-fold datasets.

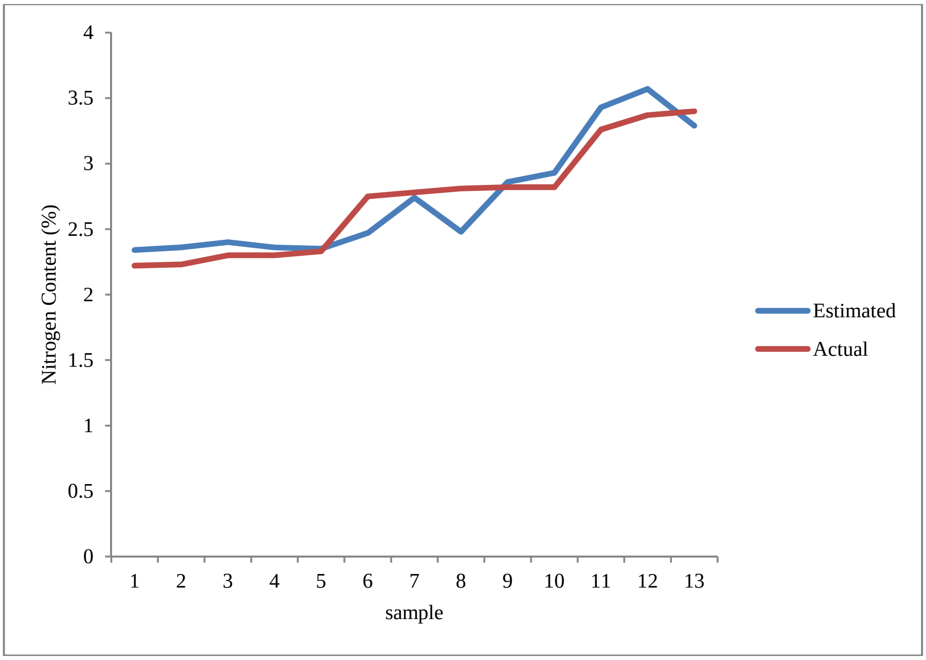

Fig. 4. Comparison between actual and estimated nitrogen content.

Figure 4 shows that the pattern of actual and estimated nitrogen content almost the same. This indicates that NIR reflectance values can be used to predict nitrogen content using ANN method. Due to the facts that we only used small size database further study is needed to justify these result.

4. Conclusion

We conducted a comparative study between measured and model estimation of Nitrogen content of rice crop based on Near Infrared (NIR) using Artificial Neural Network (ANN). We found that NIR is closely associated with the structure of the molecule in plant. Organic molecules have specific absorption pattern in the NIR region. The small reflectance value indicated that the organic molecule content in plant is high. According to experiment results, ANN can be used to predict nitrogen content of rice crop based on NIR with RMSE value of 0.32. Due to the fact that we only have relatively small size database, further study is needed to justify these result.

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